Response Reduction Factor of RC-Infilled Frames by Using Different Methods

by

Mangeshkumar R Shendkar, Sasankasekhar Mandal, Pradeep Kumar Ramancharla, Pabitra Ranjan Maiti

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Centre for Computational Natural Sciences and Bioinformatics
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Abstract

In this research paper, three dimensional four-storied reinforced concrete building is designed for the seismic zone -IV and seismically evaluated four models namely, model I (Full RC-infilled frame), model II (Corner infill at ground storey RC-infilled frame), model III (Open ground storey RC-infilled frame) and model IV (bare frame). Nonlinear static adaptive pushover analysis has been executed by using Seismostruct program. The R factor is one of the design tools to show the level of inelasticity in structures so it has great importance in the earthquake engineering field. There are different methods proposed by researchers to calculate the "response reduction factors". In this research, evaluated the R values of different structures according to different researchers method and compared with BIS code .The Response reduction factor mainly divided in to "ductility reduction factor" and "overstrength factor" were evaluated from adaptive pushover analysis and ultimately response reduction factor is evaluated for all buildings and compared with the value recommended by IS 1893 part-1 (2016). The results depict that the R factors of full RC-infilled frames are higher than the other frames. However, as per the different proposed method of researcher's the evaluated R values of bare frames are lesser than the corresponding values recommended in BIS code.

I. Introduction

Masonry infill is one of the most popular and versatile construction materials. Generally, the use of masonry infill wall mostly in RC structures is like the current construction practice in many developing countries. They are mostly elegant for an architectural point of view and cost-effective. Generally, the seismic design codes incorporate the nonlinearity presents in the structure by "response reduction factor". The R factor reduces the elastic response to inelastic, i.e., nonlinear response of a structure. In different countries it is identified as "response modification coefficient", "behavior factor" and "response reduction factor". The BIS code does not give any specific explanation on different issues like the effect of infill wall consideration, structural and geometrical configuration, irregularities, etc. Thus, the primary aim of the present study is to investigate the actual response reduction factor of RC frame structures for different infill wall configurations along with the opening in infill walls.

Keyword: Infill walls, nonlinear static adaptive pushover analysis, Response reduction factor

Alguhane et al. [1] presented the study on seismic evaluation of 5 storied RC-existing building on account of different infill configuration in frames at Madinah city. They presented four model systems i.e. model 1- (bare frame), model 2- (Frame with infill-from field test), model 3- (Frame infilled as per ASCE 41) and model 4- (Frame infilled as open ground storey according to ASCE 41).So for these all models they evaluated the response reduction factor.

Chaulagain Hemchandra et al. [6] evaluated the response reduction factor of twelve irregular Reinforced Concrete existing buildings in Kathmandu valley by using pushover analysis and relate the load path, column to beam capacity ratio components with R factor.

Shendkar Mangesh et al [13] worked on the response reduction factor of 2D RC frame for two different types of infill i.e., semi-interlocked masonry and unreinforced masonry with and without opening in infill and showed that the R-value effectively decreases by considering opening in the infill.

Shendkar and Pradeepkumar [14] presented the numerical simulation of RC semi-interlocked masonry (SIM) and unreinforced masonry (URM) frame. In which response reduction factor is evaluated by using pushover analysis in seismostruct software and the R-value shows higher in RC SIM panel frame as compared to RC URM panel frame. Nishanth M. et al [17] evaluated the actual value of R factor for OMRF and SMRF RC frames with different zones. In which they modeled 2D RC regular frames like 4, 7, 10, 13 and 16 stories and analyzed by using pushover analysis and concluded that, R-value decreases as seismic zone increases, the overstrength factor of SMRF is higher than OMRF.

In this research, the following endeavors are adopted.

- To find the realistic response reduction factor of RC-infilled frames according to different proposed methods for different infill configuration along with the opening in infill walls by using adaptive pushover analysis.
- To compute the actual R factor evaluated from different proposed methods and compare with the values recommended by BIS code.

II. Adaptive pushover analysis

In recent years, the application of pushover analysis is generally used to check the nonlinear response of structures. It represents a principled alternative solution for nonlinear dynamic analysis of structures. In case of multistoried structure, ignoring the effect of higher modes is one of the limitations of such approaches. So the (Kalkan and Kunnath 2006 [9] and Gupta and Kunnath 2000 [8]) proposed to consider higher mode effects depending on adaptive pushover procedures which includes the increasing variation in the dynamic properties like time period, frequency etc. In which, the applied load is revised at every incremental action depending on the current dynamical properties of structure. In an attempt to avoid the previous inconvenience, single-run adaptive pushover procedures investigated by many researchers. One of the modal components is chosen as a base for the adaptive pushover procedure

Researcher Antoniou and Pinho [3] employed a force-based adaptive pushover analysis, in which, the lateral load is continuously revised at each single step during the eigen-value analysis. SRSS method is used to combine the responses of each mode.

In this advanced static analysis method, spectral amplification part is also important for updating the load vectors. As per the literature for adaptive pushover case, one can introduce the record of earthquake ground motion and defines the level of damping.

In present study, for spectral amplification considered accelerogram time-history is the Chi-Chi earthquake (Taiwan) Date: 20 September, 1999 taken from PEER database.

III. Response reduction factor

The R factor is generally used to minimize elastic response to inelastic response structures. In other words, the response reduction factor is defined as the ratio of elastic strength to inelastic design strength. The response reduction factor is also named as a "response modification factor" and "behavior factor". From the existing literature, the R factor mainly depends on 3 factors, i.e., ductility factor, overstrength factor, and redundancy factor. And it is mathematically expressed as:

$$R = R_{\mu} \times \Omega \times R_R \qquad (1)$$

R = Response reduction factor, R_{μ} = ductility reduction factor, Ω = overstrength factor and R_R = redundancy. But according to BIS code provisions; it is mathematically represented as [4]

$$2R = R_{\mu} \times \Omega \qquad (2)$$

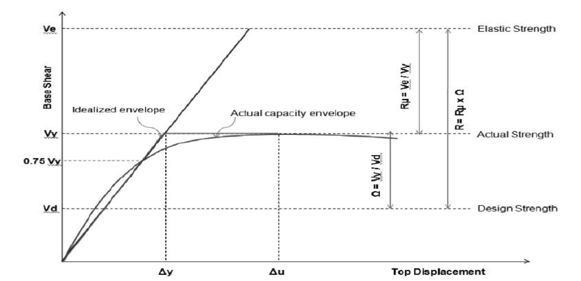

Fig 3.1 Interrelation between Response reduction factor, over-strength and ductility reduction factor

According to, ATC-19 [2] the product of the ductility reduction factor and the over-strength factor is the response reduction factor.

A. Ductility Reduction Factor (R_{μ})

The ductility reduction factor provides a measure of the global nonlinear response of a structure. It mainly depends on, ductility and fundamental time period of any structure. The displacement ductility

$$\mu = \frac{\Delta_{max}}{\Delta_y} \qquad (3)$$

Δ_{max}= maximum displacement corresponding to peak base shear of pushover curve and Δ_y = yield displacement, calculated by reduced stiffness method as shown in figure 3.2.

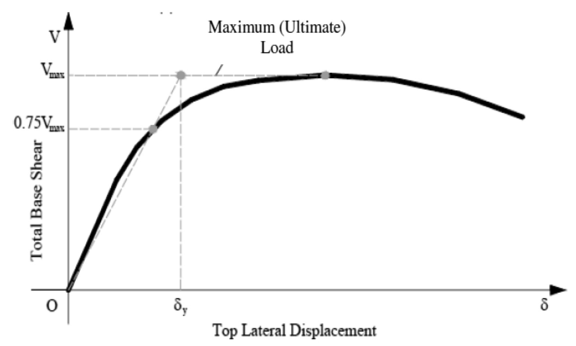

Fig 3.2 Reduced stiffness method (Park, 1988)

According to ATC-19, there are various methods to evaluate the ductility reduction factor as follows:

1. The R-μ-T relationships developed by researcher Newmark and Hall [22] used to evaluate R_μ as follows:

If, Time period < 0.2 Seconds
If, 0.2 seconds < Time period < 0.5 Seconds
If, Time period > 0.5 Seconds

$$R_\mu = 1$$
$$R_\mu = \sqrt{2\mu - 1} \quad (4)$$
$$R_\mu = \mu$$

2. Researcher krawinkler and nassar (1992)

Researcher krawinkler and nassar developed the R-μ-T relationships in 1992 on the basis of statistical analysis of 15 United States ground motion records from earthquake magnitude range 5.7 to 7.7. This relation is related to strain hardening ratio.

$$R_\mu = \left[C(\mu - 1) + 1\right]^{\frac{1}{C}} \quad (5)$$

$$C(T,\alpha) = \frac{T^a}{1+T^a} + \frac{b}{T} \quad (6)$$

Where, C is the constant depends on period (T) and strain hardening parameter (α). Regression constants a and b depends on strain hardening parameters given below table 3.1

Table 3.1 Regression constants based on strain hardening

Strain hardening value	Regression Constants	
(α)	a	b
0%	1	0.42
2%	1	0.37
10%	1	0.29

3. Researcher Mirinda and Bertero (1994):

Researcher Mirinda and Bertero reworked on the R-μ-T relationships in 1994 on the basis of study on 124 ground motions recorded on different soil conditions like rock, alluvium and soft soil sites. The equation of ductility reduction factor is:

$$R_\mu = \frac{\mu - 1}{\phi} + 1 \quad (7)$$

$$\phi = 1 + \frac{1}{12T - \mu T} - \frac{2}{5T} e^{-2(\ln(T) - 0.2)^2} \quad (8)$$

B. Overstrength Factor

It is measure the reserved strength present in a structure. It may be expressed as

$$\Omega = \frac{V_y}{V_d} \quad (9)$$

V_y = ideal yield base shear and V_d = the design base shear.

The main sources of overstrength factor are: (i) material strength (ii) load factors and its combination (iii) participation of nonstructural element like infill walls, and (iv) redundancy

C. Redundancy factor

Redundancy is usually defined as the gap between local yield point to the global yield point of a structure. Any building should have a high degree of redundancy for lateral resistance. In this study, the redundancy factor is incorporated into the overstrength factor.

Recommended values of 'Response reduction factor' by IS1893 (Part-1): 2016

Frame System	R value
OMRF	3
SMRF	5

IV. Model Description

For this study, a 4-storey with 3 bay frames in both direction i.e., X and Y direction each span 4 m three-dimensional building and floor height 3m, symmetrical plan is considered. The building being studied is situated in seismic zone 'IV' and designed for lateral earthquake load. The building is modeled by using seismostruct software. Models are studied for comparing the performance of RC frame structures for different infill configuration with considered opening to make as realistic practical models are as follow:

1. Full RC-infilled frame in both direction
2. Corner infill at ground storey RC-infilled frame in both directions
3. Open ground storey RC-infilled frame in both direction
4. Bare frame in both direction

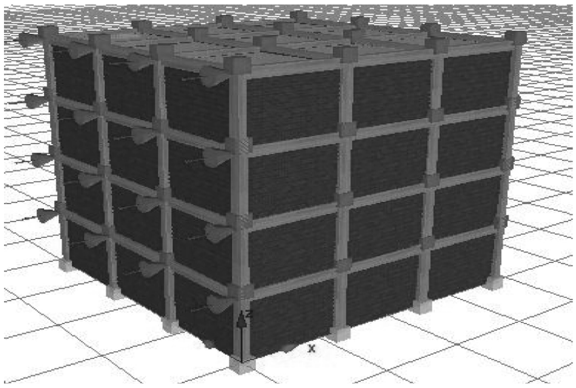

Fig 4.1.a Full RC-infilled Frame

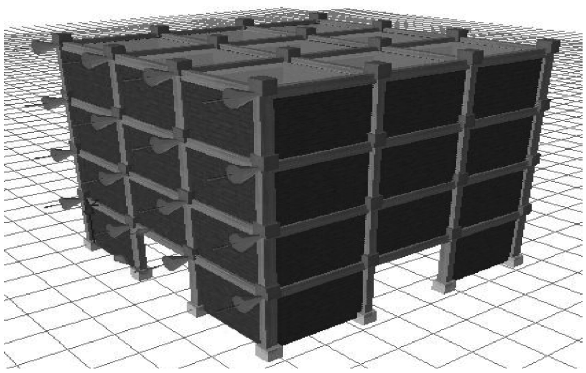

Fig 4.1.b Corner Infill at Ground Storey RC-infilled frame

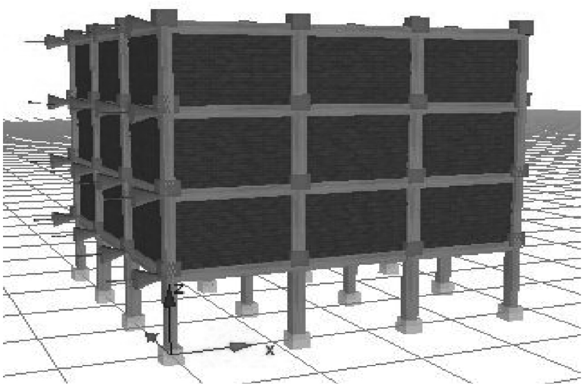

Fig 4.1.c Open Ground Storey RC-infilled Frame

The models of the building are shown in Fig 4.1 and Fig 4.2 shows the plan of the building. Material and sectional properties as shown in Table 4.1

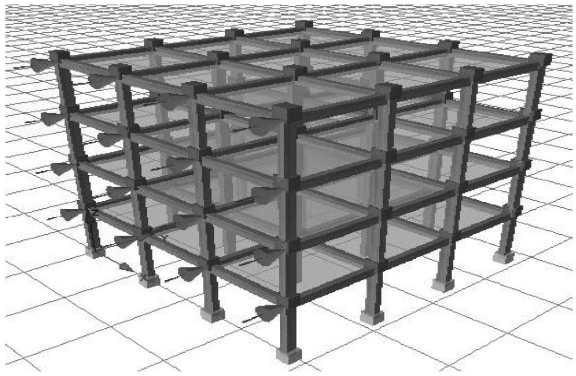

Fig 4.1.d Bare Frame

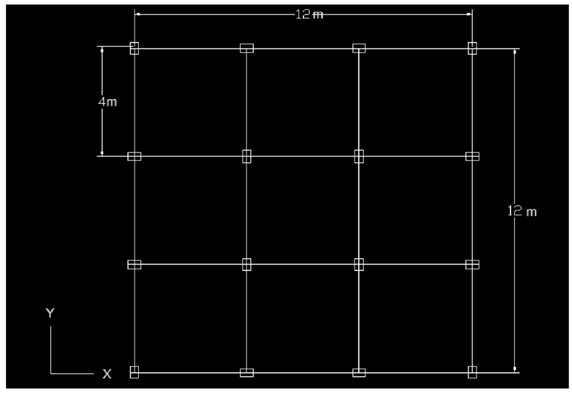

Fig 4.2 Arrangement of the building in planar way

Table 4.1 Structural details of the building

Type of structure	Special moment resisting frames
Number of storey	4
Seismic zone	IV
Floor Ht.	3m
Bay length	4 m along the X direction and Y direction
Infill wall	230 mm
Comp. strength of masonry	5 MPa
Young's modulus of masonry	2750 MPa
Type of soil	Medium stiff soil
Column size (mm)	300 X 450
Beam size (mm)	250 X 450
Slab depth (mm)	150
Live load (kN/m^2)	3
Material	M -25 grade concrete and Fe-415 reinforcement
Damping in structure	5%
Importance factor	1.5

4.1 Infill Panel Element (Inelastic):

Infill element is characterized by 4 axial struts and 2 shear springs, as shown in Figure 4.3. This element can define in physical characteristics of infill, strut curve and shear curve parameters. Four node panel masonry elements were developed by the Crisafulli (1997) [5]. It accounts for separately shear and compressive behavior of masonry infill and adequately represents the hysteretic response. It shows the high level of accuracy. This model is also known as "double strut nonlinear cyclic model". The presence of an opening in infill will directly affect on structural integrity of structures, the effect can be incorporated by minimize the width (diagonal strut). The stiffness reduction factor to consider opening effect in infill in numerical modeling is given by

$$W_{do} = (1-2.5A_r) \times W_d \quad (6)$$

Where Ar = The Ratio of opening area to the overall i.e., face area of infill. The equation no. 6 is valid for opening in wall greater than 5% and lesser than 40%.In this paper opening in infill considered as 1.2m X 1.2m and 1m X 1m= 2.44 m^2 so that means approximately 20 % opening area is considered in the infill.

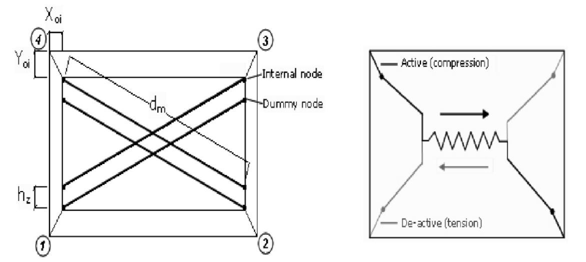

Fig 4.3 Inelastic Infill Panel Element (Crisafulli 1997)

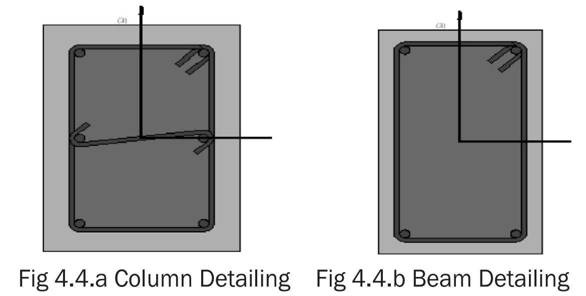

Fig 4.4.a Column Detailing Fig 4.4.b Beam Detailing

Table 4.2 Column dimensions and detailing

3	Size(mm)	Main Reinforcement	Shear Reinforcement
All columns of the building	300 X 450	4 nos. of 16 mm dia. at corner and two nos. of 16 mm on the longer side.	8mm Dia. @ 100 mm c/c

Table 4.3 Beam dimensions and detailing

Beam	Size(mm)	Main Reinforcement	Shear Reinforcement
All beams of the building	250 X 450	2 nos. of 16 mm diameter @ top as well as bottom	8mm Dia.@ 100 mm c/c

V. Results and Discussion

1. Pushover Curves:

The utilization of nonlinear static analysis came into practice in1970's but the potential of nonlinear static pushover analysis method has been identified during the last two decades. In this study, four-node panel element infill models are used for numerical simulation of frames and new approach i.e., static adaptive pushover analysis has been used for simulation purpose. The several parameters like strength, ductility, R factors are evaluated from adaptive pushover analysis curves. Thereby, the significance of infills, which play an important role in the RC frame, has been quantified. Using these pushover curves, one can get the capacity of the whole structure. From Fig 5.1, it is inferred that RC-infilled frames have the maximum capacity as compared to bare frames because of the influence of infill in the seismically active zone.

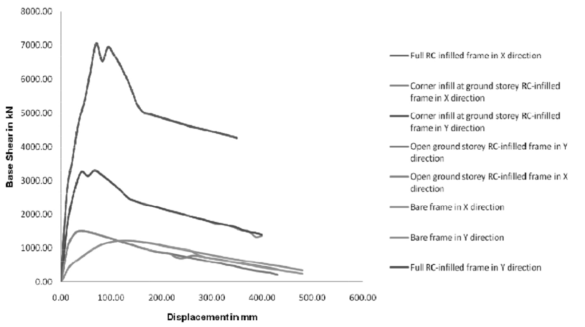

Fig 5.1 Comparisons of Pushover Curves

2. Base Shear

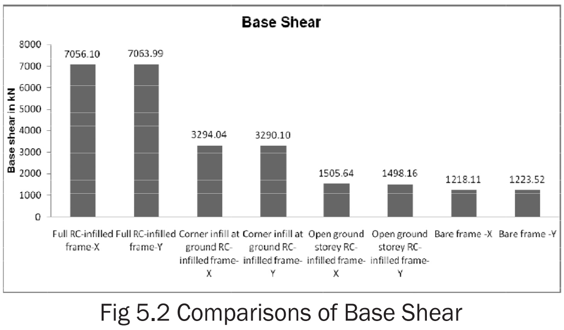

Fig 5.2 Comparisons of Base Shear

Base shear is lower in bare frames as compared to Full RC-infilled frames. Due to the symmetry of building in both direction, i.e., X and Y direction, there is a very small variation in base shear of different models in both direction i.e., X and Y. Averagely 114.45 % base shear increases in Full RC-infilled frame as compared to corner infill at ground RC- infilled frame. Similarly, in case of corner infill at ground RC- infilled frame and open ground storey i.e., soft storey RC-infilled frame, there is a variation of base shear by averagely 119.19 % and the base shear increased by averagely 23.02 % in open ground storey i.e., soft storey RC-infilled frames as compared to the bare frame.

3. Ductility

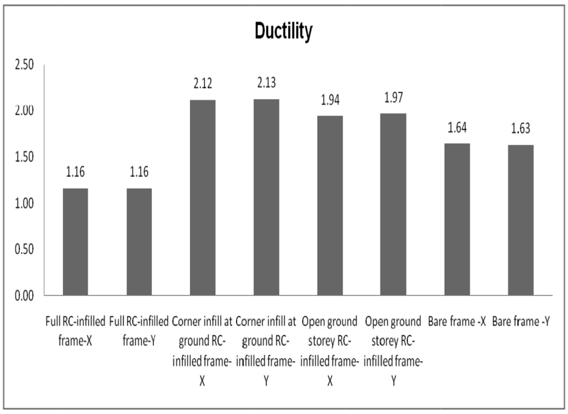

Fig 5.3 Comparison of Ductility

Using Equation (3), ductility is evaluated from Fig 3.1. Ductility obtained is higher in corner infill at ground RC-infilled frame as compared to all other frames because, few infill panels are present at the corner of ground level and the remaining portion of the ground storey is empty so due to the mutual interaction of infills at ground storey gives minimum yield displacement. Similarly, in case of open ground storey, also known as soft storey RC-infilled frame, the ductility is almost nearest to corner infill at ground RC- infilled frame because of nearly same infill configuration at a ground storey. Averagely 19.63 % ductility increases in open ground storey RC-infilled frame as compared to bare frame because of absence of infill panel at ground level (i.e., sudden change in stiffness) and another reason is that, initial stiffness of open ground storey RC-infilled frame has more as compared to bare frame so due to that reason yield point of open ground storey RC-infilled frame has less as compared to bare frame.

4. Ductility Reduction Factor

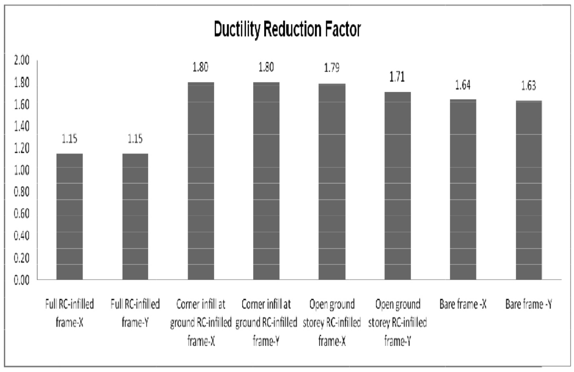

Fig 5.4.a Comparison of Ductility Reduction Factors according to Newmark and Hall (1982)

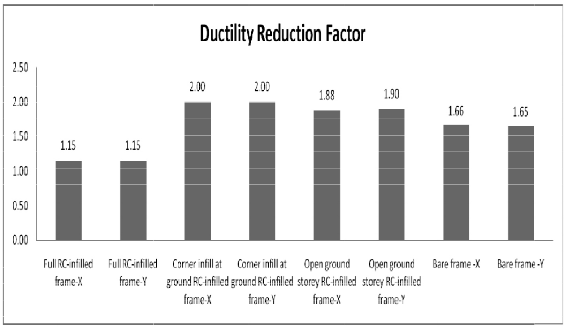

Fig 5.4.b Comparison of Ductility Reduction Factors according to krawinkler and Nassar (1992)

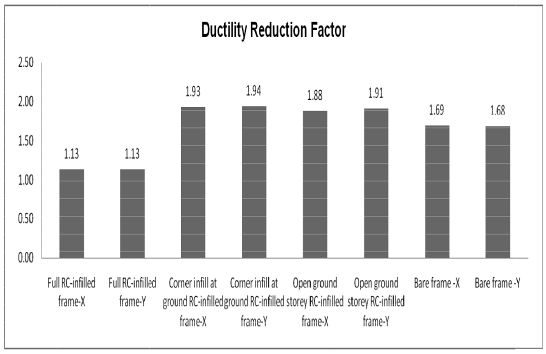

Fig 5.4.c Comparison of Ductility Reduction Factors according to Miranda and Bertero (1994)

Using Equation (4), the ductility reduction factor is evaluated on the basis of the ductility and time period. The ductility reduction factor is higher in corner infill at ground RC- infilled frame as compared to all other cases as we saw in ductility case. Averagely 2.85 % ductility reduction factor increases in corner infill at ground RC-infilled frame assimilate to open ground storey RC-infilled frame. In case of bare frame, the ductility reduction factor is same as ductility because bare frame goes under a long-period structure. As per figure 5.4.a, 5.4.b, 5.4.c, the ductility reduction factor is slightly increases in case of corner infill at ground storey RC-infilled frames, open ground storey RC-infilled frames and bare frames according to the proposed method of researchers krawinkler and Nassar (1992), Miranda and Bertero (1994), as compared to researcher newmark and hall (1982)

5. Time period

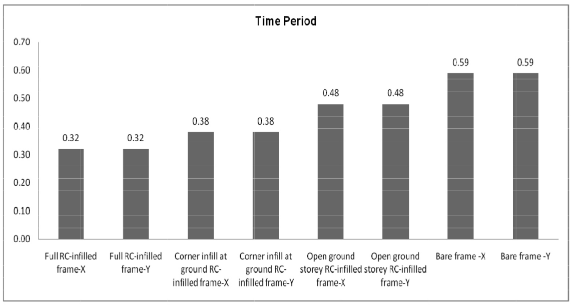

Fig 5.5 Comparison of Time Period

The time period is higher in a bare frame as compared to all other frames because infill panels are not present in the frame so resistance to the vibration of a structure is minimum. Nearly 84.37 % time period increases in a bare frame as compared to full RC-infilled frame. In case of corner infill at ground RC-infilled frame and full RC-infilled frame, there is a variation of the time period by 18.75 %.

6. Overstrength Factor

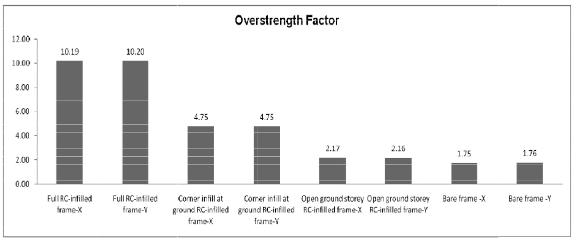

Fig 5.6 Comparison of Overstrength Factor

Using Equation (5), overstrength factors are evaluated based on Fig 3.1. The overstrength factor is higher in full RC-infilled frame as compared to all other frames because infill panels are present in the frame. Averagely 119.90 % overstrength factor increases in corner infill at ground RC-infilled frame as compared to open ground storey i.e., soft storey RC- infilled frame due to the number of infill panels more at a ground storey. In case of open ground storey RC-infilled frame and bare frame, there is a variation of overstrength factor by averagely 23.42 % because number of infills present in open ground storey frame is more than bare frame.

7. Response Reduction Factor

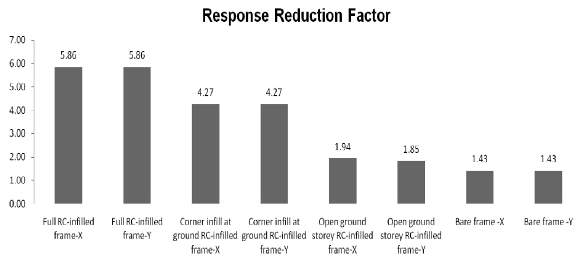

Fig 5.7.a Comparisons of Response Reduction Factors according to Newmark and Hall (1982)

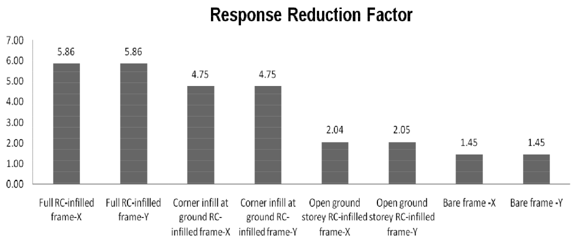

Fig 5.7.b Comparisons of Response Reduction Factors according to krawinkler and Nassar (1992)

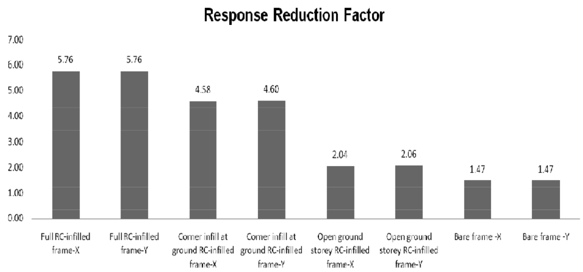

Fig 5.7.c Comparisons of Response Reduction Factors according to Miranda and Bertero (1994)

Using the Equation (2), R factor is evaluated based on Fig 3.1. The Response reduction factor is higher in full RC-infilled frame as compared to all other frames. Generally, R factor is more depends on overstrength factor so the behavior of both factors for all frames is quite similar as per figure 5.6 and figure 5.7. The R factor increases in full RC-infilled frame as compared to corner infill at ground RC- infilled frame by averagely 28.69 %. The R factor is very less in bare frame as compared to all other frames due to absence of infill walls. As per figure 5.7.a, 5.7.b, 5.7.c, the response reduction factor is slightly increases

Table 5.1 Comparison of parameters by different methods						
Name of Models	R factor			Ductility Reduction Factor		
	Newmark and Hall (1982)	Krawinkler and Nassar (1992)	Miranda and Bertero (1994)	Newmark and Hall (1982)	Krawinkler and Nassar (1992)	Miranda and Bertero (1994)
Full RC-infilled Frame-X	5.86	5.86	5.76	1.15	1.15	1.13
Full RC-infilled Frame-Y	5.86	5.86	5.76	1.15	1.15	1.13
Corner infill at ground storey RC-infilled Frame-X	4.27	4.75	4.58	1.8	2.0	1.93
Corner infill at ground storey RC-infilled Frame-Y	4.27	4.75	4.60	1.8	2.0	1.94
Open Ground Storey RC-infilled Frame-X	1.94	2.04	2.04	1.79	1.88	1.88
Open Ground Storey RC-infilled Frame-Y	1.85	2.05	2.06	1.71	1.9	1.91
Bare Frame-X	1.43	1.45	1.47	1.64	1.66	1.69
Bare Frame-Y	1.43	1.45	1.47	1.63	1.65	1.68

in case of corner infill at ground storey RC-infilled frames; open ground storey RC-infilled frames and bare frames according to the proposed method of researcher's krawinkler and Nassar (1992), Miranda and Bertero (1994), as compared to researcher Newmark and hall (1982).

8. Damage of frames

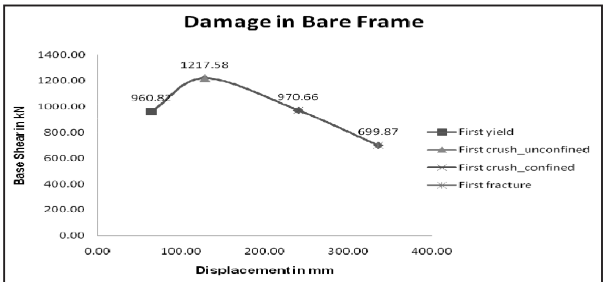

Fig 5.8 Damage pattern in the bare frame

To check the damage patterns of different frames the performance criteria based on material used in the present numerical simulation are (i) crushing strain limit for unconfined concrete: 0.0035, (ii) crushing strain limit for confined concrete: 0.008, (iii) yield strain limit for steel: 0.0025, (iv) fracture strain limit for steel: 0.06 [20]

As per figure 5.8 in a bare frame, first yielding of steel occurred at base shear 960.82 kN and displacement 64 mm. This yield displacement is more as compared to all other frames because, low stiffness in bare frame. First crushed unconfined concrete i.e., spalling of cover concrete occurred at base shear 1217.58 kN and displacement 128 mm, first crushed confined concrete i.e., core portion of concrete occurred at 970.66 kN and displacement 240 mm and the first Fracture point is present at base shear 699.82 KN and displacement 336 mm ,i.e., bare frame goes up to its ultimate stage.

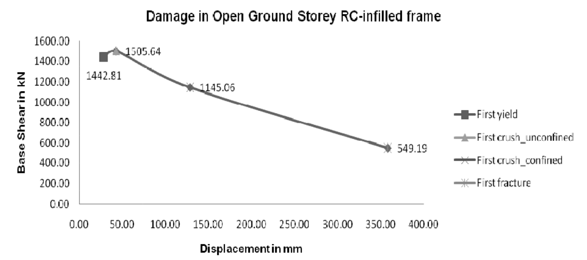

Fig 5.9 Damage pattern in Open ground storey RC-infilled frame

As per figure 5.9 in the above frame, the first yielding of steel occurred at base shear 1442.81kN and displacement 28.67 mm. This yield displacement is less as compared to bare frame because of the high stiffness in open ground storey frame as a compared bare frame. First crushed unconfined concrete i.e., spalling of cover concrete occurred at base shear 1505.64 kN and displacement 43 mm, first crushed confined concrete i.e., the core portion of concrete occurred at 1145.06 kN and displacement 129 mm and first Fracture point is present at base shear 549.19 KN and displacement 358.33 mm.

As per figure 5.10 in the above frame, first yielding of steel occurred at base shear 2694.10 kN and displacement 26.67 mm. This yield displacement is less as compared

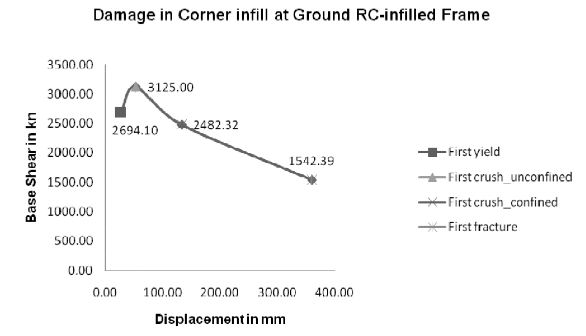

Fig 5.10 Damage pattern in Corner infill at ground RC-infilled frame

to all other frames because of the high stiffness and in this case, infill walls are present at only ground corners of the frame so other ground bays are open to take maximum drift due to that reason it gives more ductility. First crushed unconfined concrete i.e., spalling of cover concrete occurred at base shear 3125 kN and displacement 53.33 mm, first crushed confined concrete i.e., the core portion of concrete occurred at 2482.32 kN and displacement 133.33 mm and first Fracture point is present at base shear 1542.39 KN and displacement 360 mm.

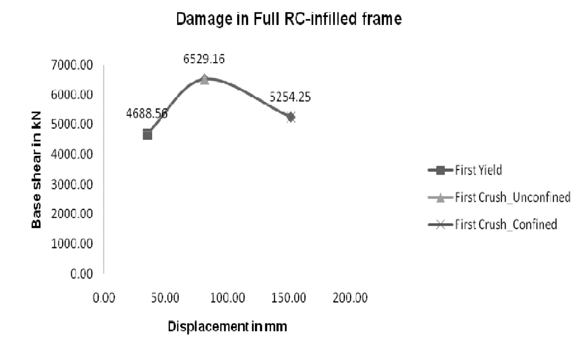

Fig 5.11 Damage pattern in Full RC-infilled frame

As per the figure 5.11 in the above frame, first yielding of steel occurred at base shear 4688.56 kN and displacement 35 mm. This frame sustains more loads as compared to all other frames. First crushed unconfined concrete i.e., spalling of cover concrete occurred at base shear 6529.16 kN and displacement 81.67 mm, first crushed confined concrete i.e., the core portion of concrete occurred at 5254.25 kN and displacement 151.67 mm.

VI. Conclusions

1. The base shear values are larger in full RC-infilled frames as compared to all other frames.
2. The incorporation of infill panels in frame structures expressively enhances the stiffness of structures and it results into the reduction in fundamental periods.
3. Ductility and ductility reduction factors are higher in corner infill at ground storey RC-infilled frames as compared to all other frames because yield displacement point is minimum compared to all other frames and in this case, infill walls are present at only ground corners of the frame so other ground bays are open to take maximum drift.
4. Ductility and ductility reduction factors of full RC-infilled frame are lowest among all four types of frames because the infills present throughout the structure so the resistance capacity increases as compared other frames as a result of it the gap between yield to maximum displacement reduces.
5. Over-strength factor is significantly affected by the presence of infill in the frame. Also, as a result of it, the response reduction factor of full RC-infilled frame is higher than the other frames in seismically active zones
6. According to present numerical study, the evaluated response reduction factor of corner infill at ground storey RC-infilled frames, open ground storey RC-infilled frames and bare frames as per the proposed methods of researcher krawinkler and Nassar (1992) , Miranda and Bertero (1994) is slightly increases as compared to researcher Newmark and hall (1982).
7. The R-μ-T relationship proposed by researcher Miranda and Bertero is the most realistic and latest method as compared to other methods. Because, the presented ductility reduction factor equation based on 124 recorded ground motions with different soil conditions.
8. The computed values of '*R*' for bare frames obtained by adaptive pushover analysis of buildings are less than the value suggested in the IS 1893 (Part I):2016.

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Mangeshkumar Shendkar
(Research scholar, IIT (BHU) Varanasi), India
Email : mangesh.shendkar94@gmail.com

Sasankasekhar Mandal
(Professor, IIT (BHU) Varanasi), India
Email : smandal.civ@iitbhu.ac.in

Ramancharla Pradeep Kumar
(Professor, EERC, IIIT Hyderabad), India
Email : ramancharla@iiit.ac.in

Pabitra Ranjan Maiti
(Associate Professor, IIT (BHU) Varanasi), India
Email : prmaiti.civ@itbhu.ac.in